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EVERY ARTIST NEEDS A BIT OF SCIENCE:
OPERATIONS RESEARCH FOR OPERATIONAL COMMANDER

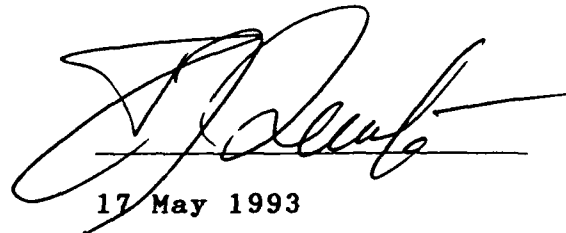
by

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The contents of this paper reflect my own personal views and are not necessarily endorsed by the Naval War College or the Department of the Navy.


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ABSTRACT

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CHAPTER I

BACKGROUND

INTRODUCTION

Frequently the operational level of war is described as a bridge between strategy and tactics and depicted using the Vann diagram with overlapping circles representing the three levels of war. Although there is no clear cut division among the three levels, the levels help commanders visualize a logical flow of operations, allocate resources, and assign tasks to the appropriate command echelon. Similarly and consequentially the functions and tasks performed by an operational-level commander at the 'upper' end, where they connect with strategy, involve the fitting of means to the task at hand, the analysis of complex situations and the designation of military objectives which when achieved, will fulfill the needs of strategy. At the 'lower' end, the operational-level commander addresses the ways in which campaigns are designed and pursued in a theater; determining when and where to fight, disposing forces in anticipation of battle and acting to get the greatest advantage of tactical actions. Field Marshal William Slim pointed out that "the prime task of the commander is to make decisions."¹ He continued by describing more precisely what must be done:

"What you have to do is to weigh all the various factors recognizing that in war half your information may be wrong, that a lot of it will be missing completely and that there are all sorts of elements over which you have not control... (*The commander must*)... weigh all these things and come to a decision as to what... to do."²

Decision making is a vastly more complex process at the operational

level than it is at the tactical level. The tactical commander's decisions concern the current battle and efforts to shape the next day's battle. The operational-level leader is concerned with a series of tactical actions over expanded time and distances. Accordingly, he must work from greater uncertainty than does the tactical commander. An operational commander is both a leader and a manager. In both roles he is the ultimate decision maker. As a leader, the operational commander inspires and earns trust of his subordinates by making the best informed decisions and executing them appropriately. As a manager, the operational commander allocates resources to ensure that maximum combat power is brought to bear at the decisive point in time and space to accomplish the mission. The technological advances offer to an operational commander a variety of resources capable, in varying degrees, of accomplishing an assigned task. Such resources are never limitless and the operational commander must make decisions on the most effective way to use them. Additionally, even the most sophisticated technology does not remove the risk inherent in a conflict. Nevertheless, the operational commander is expected to make the most correct decisions possible, 'somehow' factoring in the risk and uncertainties. *Operations research* can greatly assist the operational commander in making these decisions, and in planning, direction, and execution of his operations.

DEFINITION

"*Operations research* (emphasis added) is a scientific method of providing executive departments with a quantitative basis for decisions regarding the operations under their control."³

Numerous synonyms for operations research are in common use. The British use *operational research* and a frequent American substitute is *management science*. As its name applies, operations research involves 'research on operations'. It is applied to problems that concern how to conduct and coordinate the operations or activities within an organization. The approach of operations research is that of the scientific method. Thus, the process begins by carefully observing and formulating the problem and then constructing a scientific model that portrays the essence of the real problem. It is then hypothesized that this model is a sufficient representation of the salient features of the situation, so that the results obtained from the model are also valid for the real problem. This hypothesis is then modified and verified by suitable experimentation or testing. However, to be successful, operations research must also provide positive, understandable conclusions to the decisionmaker (read operational commander) when they are needed. It attempts to resolve the conflicts of interest, such as competition for scarce resources, among the components of command in a way that is the best for the organization as a whole. It does this by searching for an optimal solution to the problem under consideration. Rather than being content with merely improving the status quo, the goal is to identify the best possible course of action. The primary focus of operations research is on decision making. The principal results of the analysis must have direct and unambiguous implications for operational commander's actions. This is not to imply that an operational commander should base his decisions exclusively on computer results of an analysis. Rather the operational commander's decision making

process and problem solving capability can be greatly enhanced through the proper use of quantitative analysis.

SCOPE

This paper will demonstrate how prudent use of *operations research* can assist the operational commander in decision making, planning, direction, and execution of his operations. The scope of this paper will be limited to operational-level problem solving and will not include strategic planning or acquisition policy uses of operations research. The paper's technical level is aimed at the practitioner of the operational level of war and not at the practitioner of operations research. However, the paper may be useful to the latter by suggesting what the operational commander really needs from the analyst. The paper will demonstrate, in broad and simple terms, some of the myriad of operations research tools available to the operational commander.

ORGANIZATION

This paper is organized into five chapters. First, a brief historical perspective on the use of operations research is presented. Next, the use of operations research is discussed as a force multiplier and several examples of applicable types of operational problems are presented. In the fourth chapter, common pitfalls and limitations to the use of operations research are provided. The last chapter offers conclusions on what the operational commander should expect from operations research and, in turn, what the analyst needs to best support the operational commander.

CHAPTER II

HISTORICAL APPLICATIONS OF OPERATIONS RESEARCH

The application of *operations research* can be traced back many decades, when early attempts were made to use a scientific approach in the management of organizations. However, the beginning of the discipline called operations research has generally been attributed to the military services early in World War II. The war effort caused an urgent need to allocate scarce resources to the various military operations and to the organizations involved in each operation in an effective manner. Initially the British and then the American military leadership called upon a large number of scientists to apply a scientific approach to dealing with this and other strategic and tactical problems. In effect they were asked to do research on military operations, at a level that now would be termed operational. Their efforts were instrumental in winning the Air Battle of Britain, the Island Campaign in the Pacific, and the Battle of the North Atlantic.⁴

A relatively simple example of operations research in World War II which had an enormous implication on operations in the European Theater was the decision to increase the size of trans-Atlantic convoys. Data collected on the ships sunk by the German U-boats enabled the operation researchers to establish an independence between the number of ships sunk and size of the convoy. Furthermore,

the analysis pointed out inefficacy of the British Admiralty Rule concerning number of escorts assigned to each convoy. It discovered a proportional relationship between number of ships lost and the number of escorts provided. Drawing on these two results, "the Admiralty which previously... prohibited convoys of more than 60 ships gave publicity to the successful arrival of a convoy of 187 ships" and "because of the reduction in number in escort vessels, a number of anti-submarine escort vessels could be moved from the Atlantic to support the invasion of Normandy in June 1944." ⁵

The 'scientific outlook' of World War II operations research pioneers was central to their success. Their primary emphasis was on devising measures of effectiveness and collecting combat data to find out how the war going and how to improve operations. Considering the very different geographical extent of World War II, Korea, and Vietnam, as well as their different settings in time, operations research analysis in the three conflicts had remarkably similar character. World War II, with its far-flung theaters of operations, provided examples of more different kinds of combat than either Korea or Vietnam. Operations research in World War II was newer, with less of a menu of developed techniques, and in that sense was more challenging. Yet the analysis itself, in each of the three situations, exhibited many of the same themes and much of the same character. In the Vietnam conflict there was much use of operations research in the 'field'. Very interesting examples are given by Ewell and Hunt of analysis conducted from 1968 to 1970 to improve operations of the 9th Infantry Division and II Field Force (Corps level organization).⁶ In their work, the application of operations

research analysis ranged from battlefield intelligence analysis, thru optimization of Army aviation assets, to operational refinements.

The advances in computer technologies and their presence in every facet of military operations facilitates the use of operations research techniques. Coupled with the continued development of new and more powerful algorithms to solve a myriad of problems, previously thought too difficult or too costly to tackle, puts the powerful tools of operations research literally at the operational commander's fingertips.

CHAPTER III

OPERATIONS RESEARCH AS FORCE MULTIPLIER

The previous chapter provided the historical background and examples of uses of operations research. This chapter further discusses the value of operations research and provides examples of types of operational problems suitable for use of operations research techniques.

VALUE OF OPERATIONS RESEARCH TO OPERATIONAL COMMANDER

Many balk at the use of quantitative methods in the study of military operations, holding that judgement and experience- perhaps their own- have far more to offer than any calculation possibly could. Without an argument, judgement and experience are valuable guides to any human endeavor. However, war entails a great deal of uncertainty. Those who deal with uncertainty in war by playing hunches seem likely to share the fate of those who use that approach in poker or backgammon. Unfortunately, many people see quantitative models only as methods of calculating answers. In themselves, these answers rarely do much good. However, thoughtful consideration of a model's results can lead to what has been called "insights".⁷ Even a most stubborn user of judgement and experience must agree with the value of 'insight' to his decisionmaking. FM 100-5 points out that a major function of an operational commander "...involves fundamental decisions about where and when to fight and whether to accept or

decline battle."⁸ Operational art requires the commander to answer these questions:

- * What military conditions must be produced in the theater of war or operations to achieve the strategic goal?
- * What sequence of actions is most likely to produce that condition?
- * How should the resources of the force be applied to accomplish that sequence of actions?⁹
- * What are the costs and risks associated?¹⁰

Operations research can assist the operational commander in answering these questions and in making the prerequisite decisions. The value of operations research lies in problem solving and providing 'insight' as part of decision making support to the commander.

DECISION ANALYSIS

A decision is a commitment of resources to a course of action. How to make the best possible decisions is a key problem for commanders. Intuitively, one wants to weigh the alternatives available in a decision situation to find which one is best. This is often not an easy task. Very likely, the operational commander will be faced with uncertainty concerning the consequences of selecting a course of action. How does one weigh the alternatives? What is best? Decision analysis is an operations research method designed to help answer these questions. It is meant to aid the ultimate decisionmaker (commander) in the selection of a course of action.

Decisions are subjective. Different decisionmakers, when placed in identical situations, may well make different decisions. This does not mean that one would be right and the others wrong. It could be

that each of the decisionmakers has made what is the 'right' decision for them, but because of differing preferences and measures of effectiveness these 'right' decisions may also differ. This implies that decision analysis ought to incorporate the decisionmaker's preferences and selected measures of effectiveness. In fact, decision analysis provides a logical framework for the decision process which explicitly considers risk and risk preferences. Decisions are made under one of the three prevailing conditions:

1. **Certainty**- A decision is made under certainty when each alternative leads to a specific known outcome. Although this condition sometimes exists for an operational commander, it is usually associated with very routine decisions involving fairly inconsequential issues.

2. **Risk** - A decision under risk is based upon less knowledge of the outcomes than a decision under certainty. A decision is made under risk if each alternative has more than one possible outcome. However, the operational commander has information which will support the assignment of probabilities to each of the possible outcomes.

3. **Uncertainty** - A decision under uncertainty involves even less information than a decision under risk and is made under uncertainty if each alternative may lead to more than one possible outcome; however, the operational commander is unable to assign probabilities to the different outcomes.¹¹

An operational commander is likely to be faced with making a decision under any of the above conditions. Operations research has provided decision analysis methods that can greatly assist the commander in his decision process.

Under the condition of certainty, decision analysis provides methods which call for comparative enumeration of all possible alternative outcomes or application of a variety of mathematical programming models. Typically such problems are oriented toward obtaining the optimal resource allocation scheme and will be

discussed in greater detail later in this chapter.

For decisions under risk, it is expected that the operational commander will have information that will support assignment of probabilities to each of the possible outcomes. These probability values may be derived through experimentation or combat data collection and analysis. In such cases the probability assigned would be considered objective. Examples of objective probabilities are as basic as the .5 probability of 'heads' in a coin toss or as difficult to determine as the probability of kill of a T72 tank by an M1 Abrams tank at the range of 3000 meters, while both are moving. Nevertheless, each serves as an example of objective probability since the values can be derived through experimentation or analysis of actual combat data.

In cases where an objective probability value is not available, a subjective probability based on expert opinion is used. As an example, the commander of the never-executed amphibious operation in Operation Desert Storm undoubtedly assigned a probability of success to his planned operation as well as probability of failure which then allowed him to estimate casualties. Those experienced in operational level planning and command will not find making such subjective probability estimates difficult, especially when aided by timely and accurate intelligence.

One common method used in evaluation of alternatives under condition of risk is that of expected value. Simply stated, the expected value of an outcome is the 'payoff' associated with the outcome multiplied by the probability (objective or subjective) of such outcome. This simple formula has intuitive appeal. It says, in

essence, that in considering alternatives one should consider not only the possible 'payoff' associated with each alternative but also the probability of gaining each 'payoff'. These 'payoffs' and probabilities should somehow be weighed against each other. In calculating expected value, this weighing is achieved by multiplication so that a small probability will have a dampening effect on a large 'payoff' and vice versa. The expected value method permits the operational commander to select the alternative whose expected value reflects the scale of the adopted measure of effectiveness. This is done by summing the 'payoffs' of an alternative and multiplying them by the probability that it will happen. To illustrate the use of expected value in selecting alternatives two situations are presented; one using objective probabilities and the other with subjective probabilities.

In the objective probability situation, the commander must choose between using stealth aircraft to attack a group of targets or a recently developed and tested multiple-warhead missile. The stealth aircraft can destroy five targets with probability of .9 while the missile is capable of destroying six targets with probability of .7. In each case the reliability of given weapons systems and their probability of penetrating enemy air defenses have been factored in. Using the expected value method, the expected 'payoff' for the stealth aircraft is $.9 \times (1+1+1+1+1) = .9 \times 5 = 4.5$. That is, the stealth aircraft alternative is expected to 'pay off' with 4.5 targets destroyed. Similarly derived, the expected 'payoff' for the missile is $.7 \times 6 = 4.2$. If the commander's measure of effectiveness is the number of targets destroyed then he ought to select the stealth

aircraft alternative.

In the subjective probability situation, the operational commander must decide whether to use the XX Corps for the main effort with .8 probability of destroying five enemy divisions or using it to make a supporting effort, but not conducting an amphibious operation, and destroying four enemy divisions with probability of .9. The opposing, but complementary, alternative is to use the XXX Corps for the main effort with .7 probability of destroying five enemy divisions or using it for the supporting effort, with an amphibious operation, and destroying five enemy divisions with probability of .7. The alternatives are complementary in the sense that if one Corps is selected to make the main effort, the other will make the supporting effort. Using the expected value method, the expected 'payoff' for XX Corps in main effort and XXX Corps in support is $.8 \times 5 + .7 \times 5 = 4 + 3.5 = 7.5$ divisions destroyed. Correspondingly, the expected 'payoff' for XXX in main/XX in support alternative is $.7 \times 5 + .9 \times 4 = 3.5 + 3.6 = 7.1$ divisions destroyed. Again, if the operational commander's measure of effectiveness is the number of enemy divisions destroyed then the alternative of using XX Corps in main effort with the XXX Corps in support should be selected. As pointed out above, the subjective probability values were provided through the expertise of the operational commander and his staff.

In operational planning and execution, the commander and his staff will seldom operate with complete information of the situation. Through good intelligence, knowledge of enemy capabilities and capabilities of own forces, and particularly his own and his staff's expertise the operational commander should be able to formulate

objective and subjective probabilities that can be used in decisionmaking under risk.

If the probabilities cannot be estimated then the commander is forced to make a decision under uncertainty. This is the third decision condition described above. To novice decisionmakers uncertainty often brings indecision and to others an excuse for failure. This need not be, for operations research provides several methods to select alternatives under uncertainty that, in a sophisticated way, account for the decisionmaker's preferences and aversion to risk. The five most commonly used methods are: maximax criterion, minimax, maximin, minimin, and the Laplace criterion.¹²

The first four criteria, those with 'maxi' and 'mini' combinations, represent the decisionmaker's preferences for risk and can be loosely correlated as follows:

Maximax - Most optimistic (risk taker)

Minimax - Pragmatic optimist

Maximin - Hopeful pessimist

Minimin - Most pessimistic (no risk allowed)

A highly optimistic commander, with no fear of risk (e.g. General Patton), would likely use the maximax criterion by selecting the alternative that maximizes the maximum 'payoff'.

A commander with a slight degree of risk aversion would use the minimax criterion by selecting the alternative that minimizes the maximum 'payoff'.

The maximin criterion is suitable for a decisionmaker with only a slight willingness to accept risk. In this method he would select the alternative that maximizes the minimum 'payoff'.

Finally, the most pessimistic and risk-averse operational commander (perhaps General McClellan) would use the minimin criterion by selecting the alternative that minimizes the minimum 'payoff'.

The Laplace criterion, also known as the principle of insufficient reason, assumes that each outcome is equally likely and assigns equal probabilities to each. The decisionmaker then, much in the fashion of the expected value, finds the average payoff for each alternative and selects the one with the highest 'payoff'.¹³

Perhaps the best way to illustrate the use and subsequent results of the decision criteria under condition of uncertainty is to use the Commander's Estimate method for analysis of opposing courses of action as prescribed in NWP 11.¹⁴ Assuming that the selected measures of effectiveness were number of enemy units destroyed, therefore the higher 'payoff' numbers are more advantageous, the matrix representing analysis of opposing courses of action may be represented as below:

	EC#1	EC#2	EC#3	For each OCA	
				Max	Min
OCA#1	7	17	2	17	2
OCA#2	7	20	9	20	7
OCA#3	9	11	8	11	8
OCA#4	6	12	7	12	6

Application of the decision criteria is straightforward:

- * Maximax selects OCA#2 because 20 is the maximum of all maximums.
- * Minimax selects OCA#3 because 11 is the minimum of all maximums.
- * Maximin selects OCA#3 because 8 is the maximum of all minimums.
- * Minimin selects OCA#1 because 2 is the minimum of all minimums.

Using the Laplace criterion, one must first assign equal

probabilities of occurrence to each enemy course of action (i.e.1/3)
then calculate average 'payoff' for each OCA. Therefore:

OCA#1 produces $.33(7+17+2)=.33 \times 26=8.58$
OCA#2 produces $.33(7+20+9)=.33 \times 36=11.88$
OCA#3 produces $.33(9+11+8)=.33 \times 28=9.24$
OCA#4 produces $.33(6+12+7)=.33 \times 25=8.25$

Since the Laplace criterion calls for selecting the alternative with the highest average, the operational commander would select OCA#2.

The methods and techniques discussed and demonstrated above are available to assist the operational commander in making decisions under conditions he is likely to operate: risk and uncertainty. Decision analysis is a growing field and new algorithms and computer software are continually introduced. Developments in expert systems and artificial intelligence will undoubtedly make the use of decision analysis models to support the operational commander more common than ever before. Considerable work has also been done in group decision support systems to assist the staffs of operational commanders to rapidly arrive at unbiased and consensually agreed decisions.¹⁵

Nevertheless, none of the models, methods, and software can replace the logic, experience, and judgement provided by the decisionmaker (commander). However, judicious use of these tools will assist the operational commander in making more educated decisions quicker than ever. They all provide him with 'insight' to the problem and powerful tools in determining an optimal course of action.

SOLVING OTHER PROBLEMS

There are numerous decisions made by an operational commander

under conditions of certainty. Operations research stands ready with a long list of techniques and methods to assist the operational commander in making these decisions. Many of these decisions involve resource allocation problems, inventory control, transportation and network problems, assignment schemes, and queuing (waiting line) problems.

A. Resource Allocation

An operational commander is frequently faced with the problem of scarce resources and many elements of his command competing for their use. Misallocation of limited resources creates inefficiency and may cause the organization to become ineffective in accomplishment of its assigned mission. Linear programming is one technique available to the operational commander. It is perhaps the best known and one of the mostly widely used mathematical method of allocating scarce resources to achieve an objective, such as maximizing use of lift aircraft. Of course the objective may also be minimization of a resource, such as minimization of time to accomplish a complex multi-force mission. Solution of a resource allocation problem is rooted in determination of the objective to be accomplished- simply what resources the commander wants to maximize or minimize. Next, a mathematical representation of the objective is formulated as a function of the resources to be maximized or minimized. Since the resources are limited, a set of constraints is developed and represented mathematically. These may be simply the number of lift aircraft available by type, or personnel and equipment capacities of the various aircraft. Although there are 'pencil-and-paper' methods available, the proliferation of computer

software packages with linear programming capabilities makes the solution of the resource allocation problem indeed a 'non-problem'. Perhaps the most important part of the problem is the analysis of the results and conduct of sensitivity analysis to provide the commander with truly sophisticated 'insight' into the problem and means of adjusting his allocation scheme by providing limits within which the decision still remains optimal. Simply stated: sensitivity analysis offers the commander the flexibility so often required in military operations.

Formulation of a sample problem requires introduction of some mathematical ideas and is beyond the scope of this paper.

B. Inventory Control

Inventory analysis was one of the initial applications of quantitative methods and techniques studied as early as 1915.¹⁶ Inventory analysis has dominated the modeling work in development of integrated logistics models which include maintenance and transportation functions. For an operational commander the problem is to determine the correct stockage levels of various classes of supply based on consumption, storage capacities, and shipment lag time to ensure that all resources required to perform the assigned mission are available. Without a good inventory analysis the replenishment rates of already scarce resources may severely affect the sustainability of an operation. Inventory analysis is mathematically significant and capable of handling conditions of certainty and risk. Many computer software packages are available to assist the commander in making extremely accurate and timely inventory control decisions.

C. Network Analysis

Network analysis has played an important role in recent operations research because models of many real-world problems are relatively easy to conceive and construct in network form. For example, important applications of network analysis have been made in information theory, the study of transportation and trans-shipment systems, communications systems, and project (think mission) control.¹⁷ One of the fundamental problems in network analysis involves allocating flows to maximize the flow through a network connecting a source and a destination. Such a problem might be faced by an operational commander's JFACC in scheduling numerous groups of aircraft requiring refueling service at designated points, controlled ingress and egress routes, as well as other constraints. The network analysis techniques will assist the commander in making such decisions. The CPM/PERT methods have been used for many years for project planning and control. One can visualize their use in synchronization of an operation to ensure that maximum combat power is brought to bear at the decisive point in time and space.¹⁸

These are just a few samples of the myriad of problems where operations research can play an important role in assisting the operational commander in execution of his principle function, making decisions. Operations research provides the operational commander with a rational methodology for making effective and efficient decisions.

CHAPTER IV

PITFALLS AND LIMITATIONS OF OPERATIONS RESEARCH

"If you can't answer a man's argument, all is not lost; you can still call him vile names" - *Elbert Hubbard*

It is not sufficient to be aware of the value of operations research and blindly apply it to many problems facing an operational commander. As it is extremely useful to a commander to know the limitations of his own forces and weapon systems so it is for him to know the limitations and pitfalls of operations research methods. Although numerous pitfalls and limitations have been identified and available in any operations research book listed in the bibliography, only the three major pitfalls and limitations are discussed below.

Possibly the most common pitfall is associated with lack of emphasis on problem formulation. Human nature is such that when one is presented with a problem, the immediate response is to plunge into solving it without giving proper and adequate attention to thinking about the problem. Frequently this results in answering the wrong question. In haste to get started, a companion error is committed by taking the first criterion and measure of effectiveness that presents itself. That is simply because there is a tendency to measure what a system (or a set of alternatives) can do rather than what it should

do. Clearly, selection of the wrong measure of effectiveness will likely lead to a wrong decision.

Incorrect selection of method or model to use in solving a problem is another pitfall. Operations research, much like other sciences, has no unified theory that would allow universal application to all problems facing an operational commander. Because the advances in operations research were incremental, dealing with real-world problems as they presented themselves, applications of its methods suit certain classes of problems, but not others. Therefore, as an example, the application of inventory analysis methods to a network problem is inappropriate. The old adage: 'the right tool for the right job' is extremely important here.

Time, money, or lack of other resources often place limits on how far an analysis can be carried. Analysis may never be able to treat all the considerations that may be relevant to the problem at hand and the decisionmaker can wait only so long for an answer. Some of the considerations may be too intangible, especially those with political, psychological, or sociological implications. This is an inherent limitation of any analysis and must be handled with best approximations available or possible. This is truly when the decisionmaker's experience and judgement play an extremely important role and the marriage of science and art is consummated.

The operational commander must recognize these pitfalls and limitations of operations research to make the best possible

decisions. Since most solutions to his problems will be in quantitative form he must conduct the final test before accepting them. This test is often called 'the senility check'. It simply calls for the decisionmaker to ask: does this make sense?

CHAPTER V

CONCLUSIONS

This paper has provided historical applications of operations research and discussion of how operations research analysis may assist the operational commander in performing his duties as the command's principle decisionmaker. Several pitfalls and limitations of operations research analysis were also presented.

The operational commander needs to receive clear advice and recommendations based on results of the analysis. It is incumbent on the practitioner of operations research to select appropriate method and correct measures of effectiveness to answer the questions asked by the commander. The solutions must be realistic, workable, and provided in a timely manner.

The proliferation of computer software supporting operations research techniques make the use of these powerful tools easy, inexpensive, and readily available to a commander. The fast moving and technology-based warfare of today requires the operational commander to make his decisions rapidly and accurately to secure success of the operation. Judicious application of operations research provides the operational commander with a force multiplier.

The successful operational commander must still use a considerable

amount of 'art', not only in executing the operational level of war but also in use of operations research. He must be comfortable with both the artistic and the scientific elements of the subject. An analogy with the fine arts illustrates the interplay between the art and the science of applying operations research. A knowledge of scientific principles, such as chemistry of paint, the physics of light, the psychology of color, and the laws of perspective, helps the artist master fully the craft of painting. Such knowledge also distinguishes the true connoisseur from the casual Sunday museum-goer. Similarly, an understanding of the fundamentals of operations research is essential not only for the practitioner, but for the user (operational commander) who wants to make effective use of the approach. As today's operational level of war becomes more complex, demanding better and quicker decisions, the commander will not be able to operate successfully as a casual onlooker, or he himself may end up as a museum exhibit.

1. Slim, William, "Higher Command in War", Lecture, (U.S. Army Command and General Staff College, Ft Leavenworth, KS: 8 April 1952).

2. Ibid.

3. Morse, Philip M. and George E. Kimball. Methods of Operations Research. (Los Altos, CA: Peninsula Publishing, 1970), p.3.

4. Chacko, George K. Applied Operations Research/Systems Analysis in Hierarchical Decision Making (Amsterdam: North-Holland Publishing Company, 1976), v. 1, pp.22-39.

5. Ibid. p. 35.

6. Ewell, LTG Julian J. and MG Ira A. Hunt, Jr. Sharpening the Combat Edge: The Use of Analysis to Reinforce Military Judgement. Vietnam Studies (Washington, D.C.: Department of the Army, 1975). pp. 237-238

7. Hamming, Richard W., Numerical Methods for Scientists and Engineers, (Mineola, N.Y.: Dover Publications, 1986) p. 3.

8. FM 100-5 Operations, (Washington, D.C.: Department of the Army, 1986), p. 10.

9. Ibid.

10. This question was added by faculty of Operations Department, U.S. Naval War College, Newport, RI during AY 1992-93.

11. Lee, Sang M., Laurence J. Moore, and Bernard W. Taylor III, Management Science, (Dubuque, IA: Wm.C.Brown Publishers, 1985), p. 419.

12. Ibid., pp.427-430.

13. Ibid., p.428.

14. NWP 11, Naval Operational Planning (Rev F), (Newport, RI: Naval War College, 1991), p. 2-13.

15. A group decision support software Group Systems V is under study for possible adoption at the Naval War College. The author was introduced to it in NWC elective Decision Science Techniques, Spring 1993.

16. Lee, p. 354.

17. Ibid., p. 279.

18. This techniques has been used by the author at tactical level to synchronize Brigade-level operations.

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